

The Reliability and Validity of Measuring Devices for Measuring Mechanical Power

By

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Abstract

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The primary purpose of this paper is to validate a 3-D motion capture system as a reliable and valid measurement tool to be used in the practical setting for measuring bar velocity and mechanical power output. One resistance-trained, male college student participated in this study, performing ten sets of one repetition at loads of 30, 40, 50, 60, 70, and 80% of his 1 repetition maximum (1 RM) for the barbell back squat exercise. Each repetition was simultaneously recorded with a 3-D camera (EliteForm PowerTracker; EliteForm, Lincoln, Nebraska), a tether based position transducer (gold standard), and a tether-based external dynamometer. Power values were derived using the bar velocity and the system mass (external load + 88% of body mass). Both Mean and Peak Velocity and Mean and Peak Power values were used to compare the measurement devices. In addition to linear regression, and correlation data, Bland-Altman plots (Tukey mean difference analyses) were created to measure agreement in the relative difference of values from each system. There were significant correlations ($r > .80$) between all 3 methods, but were highest in mean velocity and peak velocity. Mean velocity and mean power are shown to be within the limits of agreement when comparing the 3-D camera system and LPT, while peak velocity and peak power are outside of the limits of agreement. However, a comparison of 3-D camera system and external dynamometer, shows that all 4 variables were within 95% limits of agreement. Overall, the technology in question offers a reliable means of assessing velocity and power measurements in the practical setting.

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Chapter 1: Introduction

Background

Many sports require quick and sudden bursts of movement either in the form of running, jumping, lunging or accelerating an implement as well as many other forms. These movements are created by the athletes' ability to generate large amounts of force in a short amount of time. Because of this, success in many competitive sports may be largely determined by power characteristics of the athletes. This would suggest that improvements in this physical characteristic would contribute to the progression of athletics and sport, and would provide athletes a better opportunity for success. As the need for improving mechanical power grows, so does the demand for quality research in the methods used for developing power. Because both force and velocity are components of power, it is intuitively safe to assume that improvements in each may influence the expression of power during dynamic athletic actions. However, studies have been done and are somewhat unclear as to which will have greater influence on the improvement of maximal power output. In another view, several researchers and practitioners have suggested a mixed methods approach, utilizing a combination of both high speed and high force activities to develop power. In addition, a more recent trend lies within the theory of training with the load that will maximize mechanical power output. This is the optimal combination of high force and high velocity, which is thought to be more applicable and transferable to performance in sport.

Power is defined as the product of force and velocity. Since velocity is calculated by the distance moved divided by the time interval, and work is equal to the amount of force multiplied by the distance moved, power may also be expressed as the amount of work performed in a given

amount of time. Power is measured in Watts, and is most commonly quantified utilizing high-tech force plates and position transducers. Two main variables recorded when measuring power are peak power and mean power. Peak power is specifically defined as the single instant at which power output is the highest during a given time interval throughout the concentric action of an exercise. Mean power is defined as the average of all instantaneous power output values collected over a given interval. It is important to understand that the two measurements may not be directly comparable, however, it is uncertain as to whether or not they may be related, and certainly disagreements exist as to which measurement is more important as related to other performance variables.

From a programming standpoint, if training with an “optimal load” is the most beneficial form of training, and it may be very individualized, then it would be necessary to quantify the theoretical load. This information is needed especially for coaches who do not have immediate access to complex measurement systems found in a lab setting. Practitioners must be able to utilize reliable research and confidently identify loads for their athletes that will be in the window of optimal load. While there have been numerous studies attempting to identify this variable, the results have been greatly inconsistent. This may be largely due to the great variation in research methods and reporting procedures. This paper will briefly examine a few key issues in the literature. However, there have been some well written research reviews discussing the issues in much greater depth than is required here (6, 13, 14, 18, 19, 20, 21, 22, 35, 37, 42, 51, 56).

From a practitioners perspective, as strength training and conditioning programs become more concerned with speed-strength, strength-speed, and optimal load, coaches and practitioners outside of the lab setting need a viable system to use and measure power outputs to determine if they are actually training the characteristic they intended to influence. The Power Tracker system (Elite Form, Lincoln, NE) is an effective and easy to use system that will provide athletes and coaches with immediate feedback of many different variables including the values of most concern to the development of mechanical power.

Purpose

The primary purpose of this paper is to validate a 3-D motion capture system as a valid and reliable measurement system to be used in the practical setting for measuring bar velocity and mechanical power output. These values will be useful in reporting data for research and use in the practical setting, to develop improved training concepts for coaches and athletes who need to train this physical attribute.

Hypotheses

It is hypothesized that the 3-D camera technology produces reliable and valid measures of mean and peak velocity as well as mean and peak power output during the barbell back squat exercise. In addition, it is also hypothesized that the external dynamometer also produces reliable and valid measures of mean and peak velocity as well as mean and peak power output during the barbell back squat.

Variables

The variables relevant to the current study are all measured directly and simultaneously with various technologies. Specifically, this study is concerned with mean velocity (MV), peak velocity (PV), mean power (MP), and peak power (PP). While there are many exercises and exercise variations that can be studied, the current study will examine the barbell back squat exercise, which has been used previously in studies (3, 10, 11, 53). The independent variables in the study include the loads for the back squat, which range from 30-80% of 1RM. Also, each of the measuring devices, linear position transducer (LPT), 3-D camera (3-D), and external dynamometer (ED) serve as independent variables.

Limitations

Back squat is not typically an exercise used for power because of the amount of deceleration that happens towards the end of the concentric action of the lift. However, it has been used in prior studies (3, 10, 11, 53), and because this study is aimed at examining the reliability of a measuring device, and not maximal power output as a training variable, this limitation is negligible.

Delimitations

This study is delimited to only 1 participant (male, age = 28 years), and will only measure the variables acquired from one exercise, which is a high bar back squat. This study is also only looking to validate the measurement device, and not identify an optimal load for power, generate a load-power curve, or otherwise determine a best method of training.

Assumptions

There were no assumptions made for this study.

Definitions

1. Strength-speed – strength expressed in low velocity, high force conditions
2. Speed-strength – strength expressed in moderate to high velocity, low force conditions
3. RM – Repetition Maximum
4. Mean Velocity – (MV) the average (of all instantaneous) velocity during the concentric portion of an exercise
5. Peak Velocity – (PV) the instant at which velocity is greatest during the concentric portion of an exercise
6. Mean Power – (MP) the average (of all instantaneous) power output values collected over a given interval
7. Peak Power – (PP) the instant at which power output is greatest during the concentric portion of an exercise.
8. LPT – Linear Position Transducer
9. ED – External Dynamometer
10. 3-D – 3-D Camera Device

Chapter 2 – Review of Literature

General Description of Power

Importance in Athletic Activity. Many sports require quick and sudden bursts of movement either in the form of running, jumping, lunging or accelerating an implement among many other forms. These movements are created by the athletes' ability to generate large amounts of force in a short amount of time. Because of this, success in many competitive sports may be largely determined by power characteristics of the athletes. For example, Baker and Newton (2) found that rugby players in the national division displayed 12% greater lower body maximal power when compared to their state-based counterparts, based on a barbell jump squat test. In a separate study, Baker (4) stated that national level rugby players exhibited significantly higher power output in a bench press throw at various loads as well as greater P_{\max} (maximum power output) when compared to college aged players of the state-level squad. In a study comparing starters and non-starters of a Division 1AA football program, starters produced a higher vertical jump power and static vertical jump power than non-starters (5). Additionally, Harris (27) identified a strong, positive correlation between mean and peak power from a machine squat jump and sprint times at both 10m and 30m distances. This may suggest that improvements in this physical characteristic could contribute to the progression of athletics and sport, and would provide athletes a better opportunity for success. The demand for this information has lead physiological and mechanical power to be two of the most widely studied topics in sport. Most intriguing is the development of this physical characteristic in order to contribute to the progression of athletics and sport.

In the literature, there is a great deal of discrepancy among researchers as to what information is most needed and pertinent in understanding power. Information is needed to understand the characteristics that successful athletes already possess, and what levels are required for success in each respective sporting activity. From this body of information, practitioners need more clarified information dealing with the methodology used to identify a collection of evidence based practices in developing power.

Mechanical Power Defined. Power is quantified by the product of force and velocity and is measured in Watts. Since velocity is calculated by the distance moved divided by the time interval, and work is equal to the amount of force multiplied by the distance moved, power may also be expressed as the amount of work performed within a given time frame.

Expression of Power. Siff (54) has noted that one of the central features of all motor skill is the ability to produce maximal power and power in the most efficient manner possible. Generating maximal power in the human body is a complex organization of muscular action on mechanical, neurological, and physiological levels. While each individual area has been highly studied, this paper is primarily concerned with mechanical power. Mechanical variables deal with the lever systems of the body that influence the level of force production, as well as specific technique execution that increases or decreases the efficiency of movement within the mechanical system. More specifically, the exercises performed, influence the lever systems based on the moment arm of resistance and the determination of which lever systems within the body have primary involvement. These variables will have great influence over the exercises selected in the weight room that are best suited for developing power. For example, Baker et al.

(3) have shown that jump squats and bench press throws result in greater power outputs, velocities, and muscle activation levels compared with their traditional counterparts of squats and bench press. These mechanical variables certainly have profound influence on power production, and are means for an entirely separate report, however it is necessary to examine this research at least on a minimal level to discern the specific exercises chosen for the project.

Training Theories and Methods for Developing Maximal Power

Heavy vs Light Load Training. Because both force and velocity are components of power, improvements in each may influence the expression of power during dynamic athletic actions. It is intuitively safe to assume this to be true, however, there have been several studies attempting to define which component has a greater influence on the improvement of maximal power output. Hermassi (29) states that “heavy loads are fundamental to power development, because high forces are associated with maximal motor unit recruitment according to the size principle, with units also firing at higher frequencies.” It is suggested that due to the importance of large forces to the generation of power, heavy training loads would appear to offer the optimal stimulus to the development of muscular power. A study by McBride et al. (40) showed that a heavy resistance group made better improvements in an agility test involving many stops and starts but showed less improvement in a higher velocity sprint.

Mixed Methods Approach. Other researchers and practitioners have suggested a mixed methods approach, utilizing a combination of both high speed and high force activities to develop power. Because ballistic training has less influence maximum strength levels, and heavy resistance training may not have as much of an influence on the overall rate of force

development, practitioners may choose to utilize a variety of loads over the course of a periodized plan to elicit greater power output. A mixed methods approach to training is said to have a greater overall influence on the entire spectrum of power, making it more applicable and transferrable to the athletic environment due to the development of both aspects of the force velocity relationship. (14, 20, 42, 60). Lyttle et al (39) concluded that combined training of weights and plyometrics tended to produce greater improvements in stretch shortening cycle movements. While there have been several different strategies for implementing the mixed methods approach, there is significant validation for this over the aforementioned training strategies.

Theory of Optimal Load. A more recent trend includes the theory of training with the load that will maximize mechanical power output during different training exercises. This is thought to be more beneficial for power because this load would provide the optimal combination of both high force and high velocity. There is mixed evidence to support this concept. Wilson (61) found that the group that trained with an optimal load had the best overall training effect relative to dynamic athletic performance. Newton et al (43) added support to this theory in a study with collegiate women volleyball players, stating that “during the ballistic training period, the force, velocity, and power production during the various jump tasks increased”. However, in a sample of professional team sport athletes, training with the load that maximizes individual peak power output was found to be no more effective than training at heavy loads for improving sprinting ability (27).

Perhaps one of the main challenges in addressing the benefits of training with the load that optimizes peak power output is in the identification of the optimal load. Due to inconsistent testing procedures, authors have produced a wide variety of opinions on where this optimal load occurs in the spectrum of light to heavy loads. For example, Baker (4), compared power output from a jump squat to that of a full squat to a level of upper thigh below parallel according to International Powerlifting Federation rules. It was reported that the greatest average mechanical power during the concentric portion of a jump squat to be 55-59% of full squat 1RM (repetition maximum), although 48-63% loads were all similar in output. In a study of professional rugby players, peak power output for both jump squat and bench throw was found to occur within a range of 30-50% 1RM (7). Kawamori (36) suggests that relative strength might have an influence as to the ideal load to maximize power, as he identified peak power at 70% and 80% 1RM for stronger athletes vs weaker athletes, respectively, during the hang power clean. To take it a step further, it has also been suggested that an individual determination of the optimal load must be identified in order to be most effective (31).

Velocity Specificity of Training. It has been shown that the intention to move quickly during resistance training exercises is necessary in developing strength and power (6, 46, 47). However, within the discussion of developing power, practitioners may also need to be conscious of the actual training velocity. This is the concept of velocity specificity of resistance training. This concept explains that the greatest strength improvements will occur at or around the training velocity, meaning that if exercises are practiced in the high-force, low-velocity range, then improvements will be realized mainly in that range of speed. To the contrary, if exercises are practiced in the low-force, high-velocity range, then improvements will be realized

in that range (62). In fact, the more the testing speed deviates from the training speed, improvements are diminished. McBride et al. (40) suggest that actual training velocity is a “vital component of producing high velocity capabilities” based on a study comparing heavy resistance to light resistance.

The majority of research has supported this concept. Pousson et.al. (50) showed that utilizing fast angular velocities during training had a specific influence on constant angular torque produced by the elbow flexors, whereas training with eccentric, slow, and intermediate concentric angular velocities showed no significant difference. In another study by Tillin and Folland (59), early phase explosive strength, during time limited movements improved more from explosive strength training than maximal strength training.

Some research has shown that training at fast movement velocities will have an affect on strength gains at slow velocities. Lyttle et al (39), concluded that maximal strength improvements can be realized from the use of light weights in high acceleration movements. Tillin and Folland (59) showed that while maximal strength improved to a greater extent from maximal strength training, explosive training provided a sufficient stimulus to improve maximal strength as well.

Additional research has not shown any velocity specific training responses. Murray (41), reports that after 4 weeks of velocity-specific training, peak torque production was unchanged. Although standing long jump scores improved, there were no significant differences between the slow and fast training groups.

Testing and Reporting Power

Mean vs. Peak Power. In a review of literature, there appear a few key variables that are inconsistent across many reports. This paper will briefly examine a few of the key issues in the literature. However, there have been some well written research reviews discussing the issues in much greater depth than is required here (6, 13, 14, 18, 19, 20, 21, 22, 35, 37, 42, 51, 56). One of the primary discrepancies is in dealing with peak power and mean power. Mean power is the average of all instantaneous power output values collected over a given interval. Peak power is defined as the instant at which power output is greatest during the concentric portion of an exercise. It is important to understand that both measurements are used similarly but are not interchangeable. Authors will use both to describe the same movement, so it is important to differentiate and understand which is being described. For example, Bevan (7) reports peak power when looking at a jump squat while Baker (3) reports the maximum average power in the same exercise. While it may be correct to report either variable, one may be more favorable over the other, depending on the application of data. Proper application may depend on the particular movement being studied. Among researchers, there are certainly disagreements as to their relationship with other performance variables. For example, Hori (30) suggests there is a very strong relationship between peak and mean power values, particularly in hang power clean and weighted jump squats. However, Harman et al (24) suggest that peak power was very highly correlated with VJ performance but average power was not.

From a programming standpoint, if training with an “optimal load” is the most beneficial form of training, and it may be very individualized, then it would be necessary to quantify the

theoretical load. This information is needed especially for coaches who do not have immediate access to complex measurement systems found in a lab setting. Practitioners must be able to utilize reliable research and confidently identify loads for their athletes in the window of optimal load. While there have been numerous studies attempting to quantify or identify this variable, the results have been inconsistent. This may be due in large part to the variation in research methods and reporting procedures. A study by Bevan (7), looked at rugby players performing the jump squat. Peak power at 0% 1RM (body mass only) was maximal, and significantly greater than all other load-based intensities. Baker (3) reported a maximum average mechanical power during the concentric portion of a jump squat at 55-59% of a full squat 1 RM. However, the range of 48-63% showed similar power output. These maximized power values seem to be exercise specific. For instance, Kawamori (35), found maximal peak and average power at 70% in the hang power clean. It should be noted that peak power at 70% was not significantly different than peak power at 50, 60, 80, and 90% 1RM, and average power at 70% was not significantly different than average power at 40, 50, 60, 80, and 90% 1RM.

Mean vs. Peak Velocity. Mean velocity and peak velocity, while closely related to mean and peak power respectively, provide an additional set of variables for researchers and practitioners to be concerned with. In a similar way, the values of mean and peak velocity may not be compared directly to each other, however, their importance on the calculation of mean and peak power is paramount, and may have greater or lesser relative importance with different performance measures. Also, while power is certainly the main subject of discussion with most practitioners, it may be more important to understand the velocity spectrum of each exercise to more clearly delineate between strength-speed and speed-strength, where the former occurs in

the low velocity, high force conditions, and the latter occurs in the moderate to high velocity, low force conditions (54). It may also be more important in identifying the velocity at which maximum power output occurs as opposed to a percentage of 1RM.

While MP and PP may be questioned based on the need to calculate the the two variables, MV and PV are derived directly from position and displacement data. This means that, fewer calculations are used to quantify the value, and therefore, more accurate.

Body Mass Inclusion. An additional set of variables affecting the current research revolves around the inclusion or exclusion of bodyweight into the calculation of power. This is of particular concern when measuring exercises that occur in the vertical plane of the body and require the acceleration of body mass in addition to the external load. The determination of load-power curves will be heavily influenced by this factor, and therefore could drastically affect the prescription of training loads. Hori et al. (30), compared four different methods to calculate power output during a hang power clean and weighted jump squats. They concluded that the peak and mean power outputs for all four methods were highly correlated, however, there were significant differences in results for force, power, and velocity, based on how the results were derived. Using jump squat, squat to a depth of 90 degrees at the knee, and power clean, Cormie (10) reports that the exclusion of body mass produces an underestimation of power output across the loading spectrum. In addition, the load-power relationship is affected to a greater degree at lighter than heavier loads because of the fact that the body maintains a larger percentage of the total system mass than at heavier loads. Consequently, the calculated force is reduced and affects power calculations.

This idea is taken a step further by Piscopo and Bailey (49), who suggest subtracting 12% of total body mass from the system to account for the mass of the lower leg and feet. It is thought that since the lower leg and feet are not accelerated vertically during the concentric portion of the lift, the mass of the shanks should be excluded from the system. This method has been used in previous studies in measuring power (10, 11).

Measurement Systems. In addition to the need for consistent research, coaches and practitioners require access to valid measurement systems for real-time quantification of power output. As athletes develop strength and power over time, coaches must be able to concurrently adjust training loads in order to accommodate improvements and/or the lack of training readiness. As some research has shown that load prescriptions should be individualized based on maximum power output (31), regularly gathering data is essential to making appropriate adjustments. Coaches also need reliable measurement systems for daily monitoring of power output as it pertains to evaluating daily fluctuations and fatigue. Because very few practical weight room facilities are equipped with the gold standard position transducer + force plate, other systems have been developed to make these processes more accessible to the strength and conditioning practitioner. However, before these alternative measurement systems may be used with confidence for monitoring change or potential research, their accuracy and reliability must be quantified. This is typically accomplished by comparing a new measurement device to that of the gold standard.

The force plate is often considered to be the preferred method as it directly measures the force applied to the ground through the feet (13, 26, 30). Hori et al. (30) suggest using ground

reaction force to measure power output applied to the center of mass of the system. It is thought that the displacement of the center of mass of the body accounts for an important aspect of mechanical work being performed. Therefore if the actual ground reaction force is eliminated, then the power output estimated is only the power applied to the barbell.

Linear Position Transducers (LPT) can also be used to measure power output. This technology first calculates velocity of motion from position, displacement, and time data. Then, force is calculated using the mass of the body, external load, or the entire system (body mass + external load). Finally, from velocity, and calculated force, power may be derived for mean and instantaneous values. Despite sound mathematical processes, the validity of this method has been questioned, given that the force values must be estimated (11, 13, 16, 23, 26, 30, 33, 55). Several studies have attempted to validate this method (11, 15, 23, 33,55) with somewhat mixed results. Hori (30) reported that measurements from a LPT were not a complete reflection of actual power output, particularly because this only quantifies the power applied to the barbell, and does not account for the mass of the body, which was consistent with other research (10, 11, 23). Other studies (8, 17) have validated the use of an optical encoder, which is another form of position transducer used to measure displacement and velocity data. It is thought that calculations of force and power would be considered valid if the initial displacement values are accurately defined. However, any error in the initial measurement will be magnified when calculating force and power values (5). The aforementioned studies agree that LPT measurements may not be directly comparable to force plate measurements, however, they still can be effectively used in the practical setting. Given the cost-effective means of data collection,

this is especially true when the same method is used to monitor athletes' progress over time (16, 23, 26, 30, 33, 55).

Some research has looked at using a force plate and LPT simultaneously to add precision in measuring power. When a force plate is combined with a LPT, fewer calculations are required to estimate the variables contributing to power. Velocity derived from position and displacement may be combined with the exact force generated through the ground to calculate power output directly. This method has been shown to be valid and reliable, and as previously mentioned, should be considered as the gold standard for any new system (11, 13, 30).

Summary

In many sports, power has been shown to be one of the main determinants of success. As a result, coaches spend a great deal of time working on developing power with athletes. Several theories have developed as the best way to develop power with mixed results. Up to this point in time, the most effective way to quantify power output is by using expensive lab equipment, which is not readily available to most practitioners. In addition, researchers have not been able to agree on which variables are the most important, leaving many unanswered questions about theories of training. As more cost effective methods for measuring power become available, strength and conditioning practitioners as well as researchers will be provided the opportunity to study power and methods for developing power. Hopefully with continued use of various measurement systems in the practical setting, assessment and monitoring methods will improve, and coaches will begin to gain a greater understanding of power. This should lead to improved strategies for programming the development of power.

Chapter 3 - Methods

Experimental Approach to the Problem

The reliability and validity of the 3-D camera system (Elite Form Power Tracker) to measure mechanical power output was determined by comparing mean velocity, peak velocity, mean power and peak power measurements with data simultaneously gathered by a linear position transducer (LPT), and an external dynamometer (TENDO unit).

Subjects

One male subject who was a trained weightlifter (age = 28 yrs height = 1.78 m (5'10") weight = 97.1 kg (214lbs) barbell high bar back squat 1 RM = 226.8 kg (500lbs)) volunteered for the study. The subject provided written informed consent to participate in the study as approved by the University's committee for research with human subjects.

Procedures

The subject completed 2 separate sessions in the laboratory on separate occasions. The first session included a test to determine 1RM in the barbell high bar back squat. The second session was for data collection to be used in the study. The subject was positioned with a barbell across his shoulders in a high bar position. The squat was performed to a position of thigh parallel to the floor where the inguinal fold reached the point of being level with the top of the knee, and then a return to the full standing position. The subject completed 10 sets of 1 at each prescribed load of 30, 40, 50, 60, 70, and 80% of his individual 1RM in the squat for a total of 60 repetition trials. These percentages were used because it would provide the opportunity for a large range of bar velocities. In addition, several previous studies examining the load that elicits

peak power output used this range of loads (10, 11, 27, 36, 53, 58). Each repetition was done as a separate set of 1 as opposed to a single set of 10 repetitions. Adequate rest was provided following each individual rep. The subject was instructed to perform the squat with maximal acceleration through the concentric action of the lift.

In order to validate the 3-D camera system, each repetition trial was simultaneously measured using a linear position transducer as the gold standard, as well as an external dynamometer, which has been previously shown to be a valid method of measurement for this purpose (33,55). Barbell displacement data was collected by a ceiling mounted Uni-Measure (Corvallis, OR) tether based position transducer. Barbell velocity was derived from position data. Linear position transducer signals were collected at 1000 Hz with a Biopac data acquisition system (Goleta, CA). Velocity data was analyzed using LabView software (National Instruments, Austin, TX) to derive resulting bar velocities. In addition to the position transducer, a separate external dynamometer (Weightlifting Analyzer Tendo, FiTROdyne, Bratislava, Slovakia), was also attached to the barbell, immediately next to the LPT, which was a variable sampling rate. A 3-D camera system (EliteForm PowerTracker, Lincoln, NE) was mounted on a Power Lift (Jefferson, IA) half-rack weight training station. Using specialized video capture methods at 30 Hz, power and velocity data were derived from the 3-D motion capture system. Variables collected from all measurement systems included peak and mean velocity and peak and mean power.

Statistical Analyses

Bland-Altman plots (Tukey mean difference analyses) were created to measure agreement in the relative difference of values from each system. For comparisons with the laboratory transducer, which was used as the “gold standard”, the Bland-Altman analyses used percent differences from the gold standard. For all other Bland-Altman analyses, device results were compared with the mean of both devices. All data are reported as means and standard deviations. Linear Regressions were also completed.

Chapter 4 – Results

Pearson product moment correlations for mean velocity, peak velocity, mean power, and peak power comparing all 3 methods of measurement can be seen in Tables 1-2. There were significant correlations ($r > .80$) between all 3 methods, but were highest in mean velocity and peak velocity. Bland-Altman plots, showing the mean difference of values, are seen in Figures 1-4. Mean velocity and mean power are shown to be within the limits of agreement when comparing the 3-D camera system and LPT, while peak velocity and peak power are outside of the limits of agreement. However, a comparison of 3-D camera system and external dynamometer, shows that all 4 variables were within 95% limits of agreement.

Table 1. Mean velocity and peak velocity for BB Back Squat.

	3-D - LPT	ED - LPT	3-D - ED
Mean Velocity			
r =	0.99	0.99	0.99
SEE ($\text{m}\cdot\text{s}^{-1}$)	0.025	0.009	0.029
x difference ($\text{m}\cdot\text{s}^{-1}$)	-0.015	0.015	0.030
Peak Velocity			
r =	0.99	0.99	0.98
SEE ($\text{m}\cdot\text{s}^{-1}$)	0.052	0.017	0.081
x difference ($\text{m}\cdot\text{s}^{-1}$)	-0.187	-0.105	0.081

Table 2. Mean power and peak power for BB Back Squat.

	3-D - LPT	ED - LPT	3-D - ED
Mean Power			
r =	0.93	0.99	0.92
SEE (W)	29.1	8.7	31.9
<i>x</i> difference (W)	-17.9	17.3	17.5
Peak Power			
r =	0.89	0.93	0.94
SEE (W)	95.2	74.5	59.3
<i>x</i> difference (W)	-467.3	-362.2	10.6

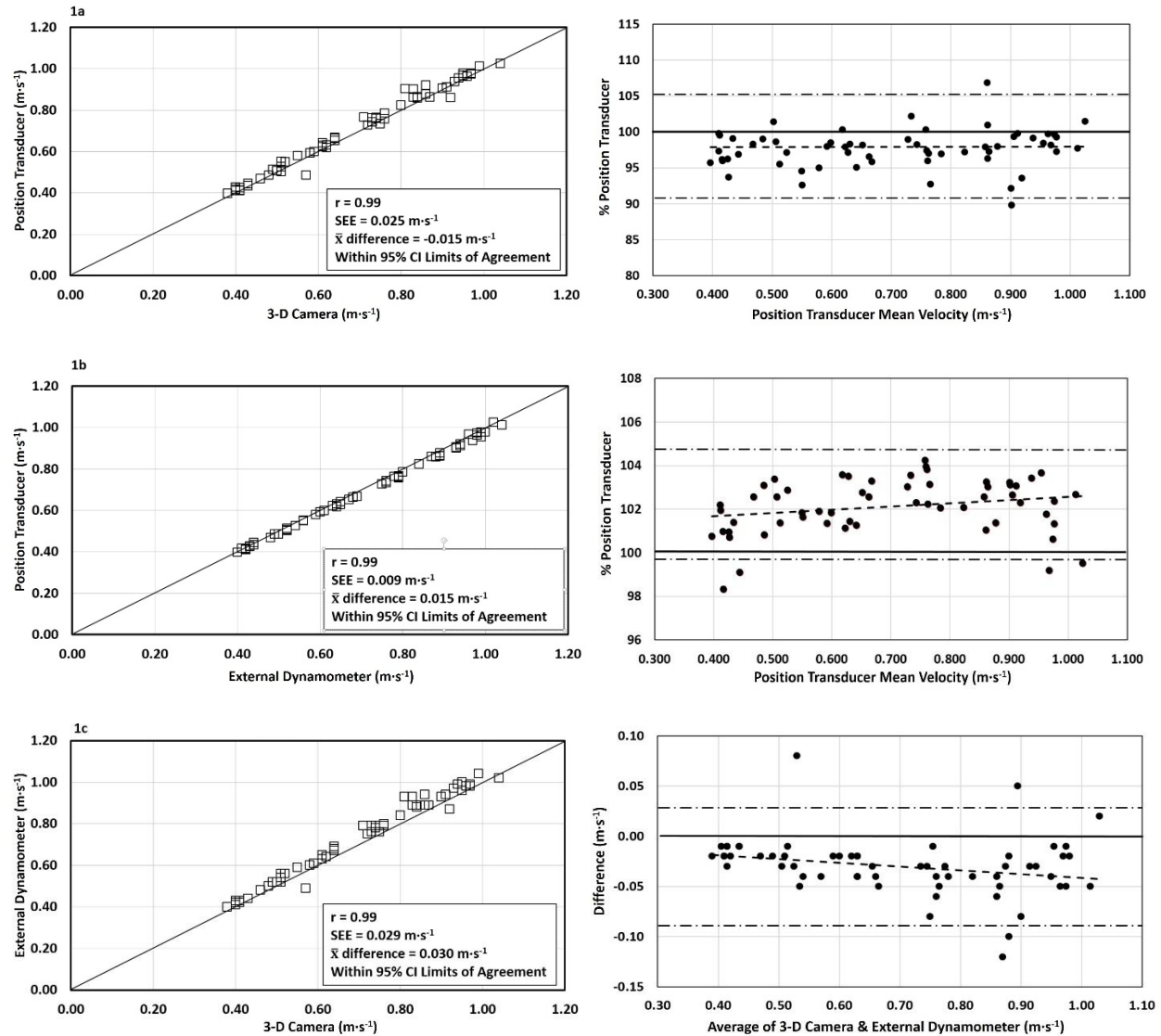


Figure 1 – Mean Barbell Velocity - Scatter plots of the linear regression analyses (left panels 1a, 1b, 1c), and Bland-Altman limits of agreement (right panels 1a, 1b, 1c) between 3-D camera and linear position transducer (1a), external dynamometer and linear position transducer (1b), and 3-D camera and external dynamometer (1c) for mean barbell velocity in the barbell back squat. The solid line (left panels 1a, 1b, 1c) represents the line of agreement for each plot. In the right panels, the dot-dash line represents 95% limits. The solid line (right panels 1a, 1b) depicts 100% of LPT values, and the mean of 3D and ED (right panel 1c). The dashed line shows the regression line for the comparisons.

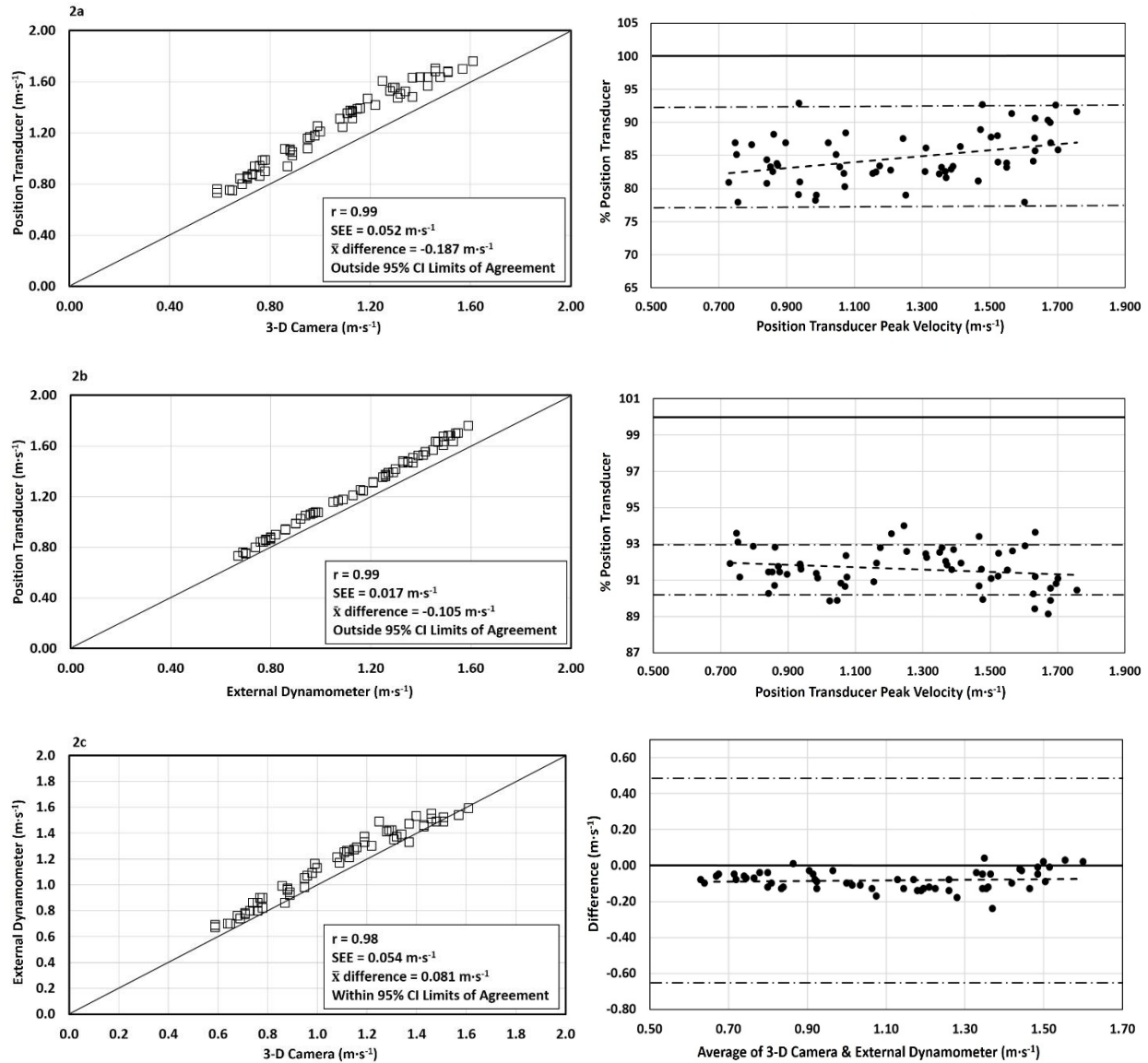


Figure 2 – Peak Barbell Velocity - Scatter plots of the linear regression analyses (left panels 1a, 1b, 1c), and Bland-Altman limits of agreement (right panels 1a, 1b, 1c) between 3-D camera and linear position transducer (1a), external dynamometer and linear position transducer (1b), and 3-D camera and external dynamometer (1c) for peak barbell velocity in the barbell back squat. The solid line (left panels 1a, 1b, 1c) represents the line of agreement for each plot. In the right panels, the dot-dash line represents 95% limits. The solid line (right panels 1a, 1b) depicts 100% of LPT values, and the mean of 3D and ED (right panel 1c). The dashed line shows the regression line for the comparisons.

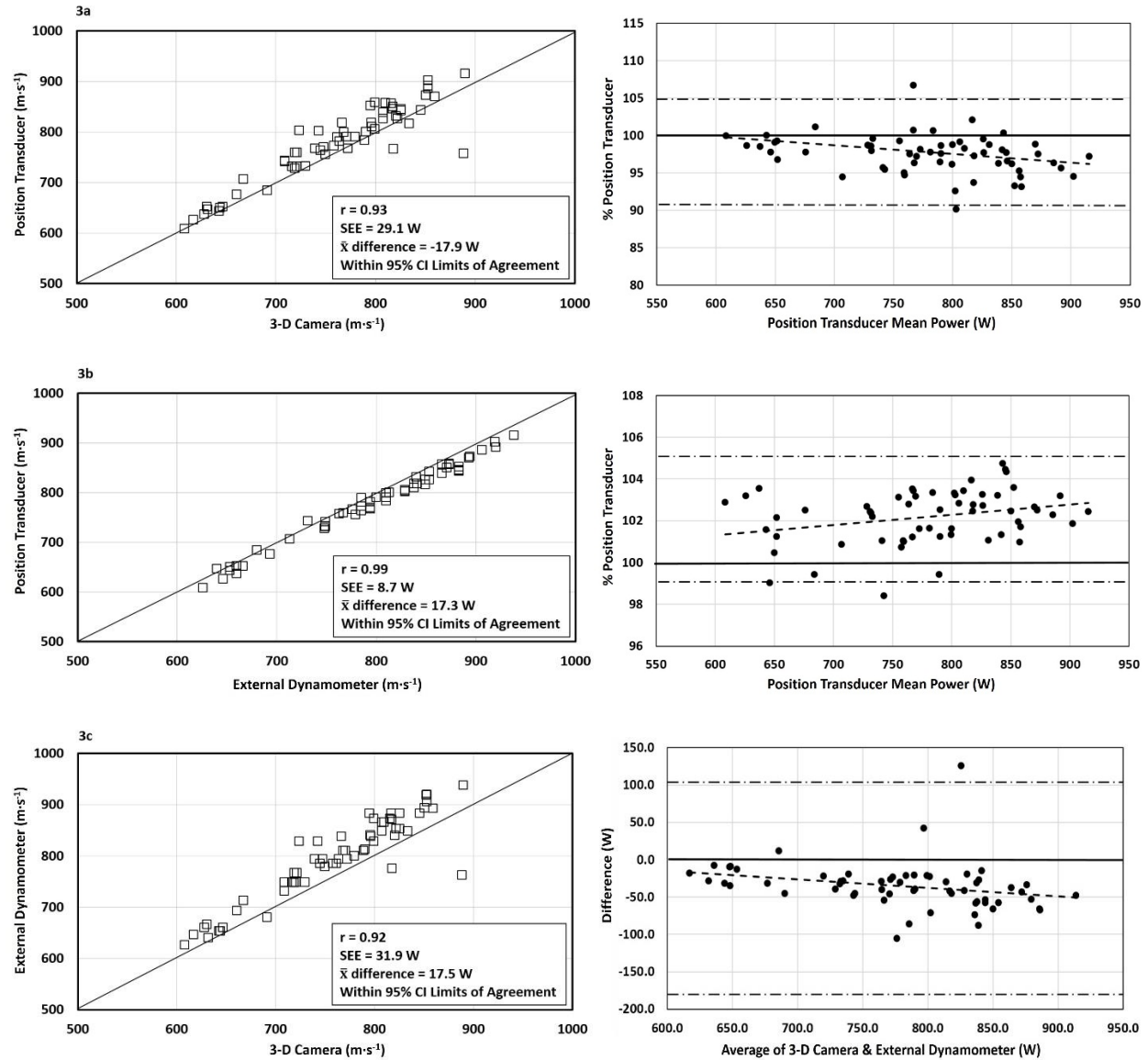


Figure 3 – Mean Power - Scatter plots of the linear regression analyses (left panels 1a, 1b, 1c), and Bland-Altman limits of agreement (right panels 1a, 1b, 1c) between 3-D camera and linear position transducer (1a), external dynamometer and linear position transducer (1b), and 3-D camera and external dynamometer (1c) for mean power in the barbell back squat. The solid line (left panels 1a, 1b, 1c) represents the line of agreement for each plot. In the right panels, the dot-dash line represents 95% limits. The solid line (right panels 1a, 1b) depicts 100% of LPT values, and the mean of 3D and ED (right panel 1c). The dashed line shows the regression line for the comparisons.

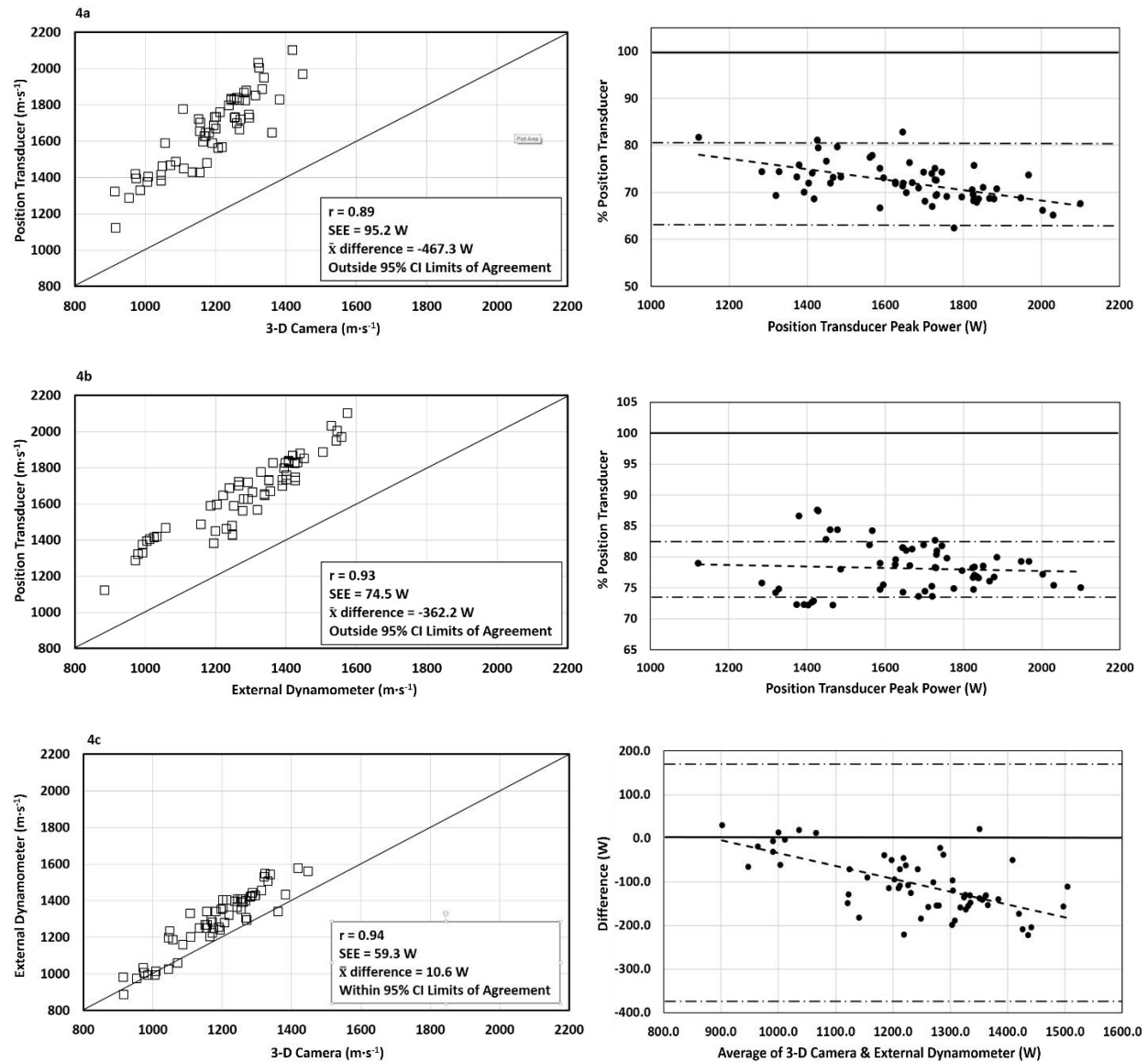


Figure 4 – Peak Power - Scatter plots of the linear regression analyses (left panels 1a, 1b, 1c), and Bland-Altman limits of agreement (right panels 1a, 1b, 1c) between 3-D camera and linear position transducer (1a), external dynamometer and linear position transducer (1b), and 3-D camera and external dynamometer (1c) for peak power in the barbell back squat. The solid line (left panels 1a, 1b, 1c) represents the line of agreement for each plot. In the right panels, the dot-dash line represents 95% limits. The solid line (right panels 1a, 1b) depicts 100% of LPT values, and the mean of 3D and ED (right panel 1c). The dashed line shows the regression line for the comparisons.

Chapter 5 – Discussion

The major finding of this study is that the technology in question offers a reliable means of assessing velocity and power measurements in the practical setting. There were significant correlations between all 3 methods of measurement for mean velocity, peak velocity, mean power, and peak power. Although calculations for mean and peak power outputs were significantly lower than the gold standard, a high r -value ($>.8$) suggests that this method is still reliable, especially for the practical setting. When compared to the external dynamometer, a method that has been shown to be reliable (33) and has been used previously in research (9), all values were within limits of agreement.

In this study, much stronger relationships were shown with mean values when comparing the 3-D camera system to the other two measuring devices. Perhaps due to the sampling rate of the technology in use, this is in agreement with previous research (30) and suggests that mean values are more reliable and valid than peak values. The r -value for both comparisons is extremely high ($r=0.99$), and the mean difference when comparing 3-D to LPT and 3-D to ED is $-0.015 \text{ m}\cdot\text{s}^{-1}$ and $0.030 \text{ m}\cdot\text{s}^{-1}$ respectively, for mean velocity. These differences are very insignificant, especially in the practical setting. When looking at power measurements, r -values are still high ($r=0.93$ 3-D & LPT and $r=0.92$ 3D & ED), and mean differences are -17.9 W and 17.5 W . When comparing athletes across time using the same technology, these values are extremely insignificant.

An additional finding of the current study is that reliability is considerably reduced when estimating force values from position data. Despite high correlation in both mean and peak velocity values, the numbers were distorted when calculations were performed to derive power

output. This is particularly true with peak power values where the mean difference was over 400W when comparing 3-D to LPT and over 300W when comparing ED to LPT.

Coincidentally, when comparing the 3-D to ED, mean difference was significantly reduced (10.6 W). As mentioned by previous authors (23, 30), this study agrees that despite strong relationships between the 3 methods, they must be viewed as different, and practitioners should avoid direct comparison. Each measurement device has different sampling rates and calculation methods for determining selected values. Both the 3-D and ED produced power values that were significantly lower than LPT. However, that does not mean the values are incorrect. It is thought that estimations of force are similar between the two devices, which may be why they are statistically more comparable.

In conclusion, the present study shows very strong relationships between the 3 methods of measuring bar velocity and power output for the back squat. Both mean velocity and mean power were within limits of agreement in all 3 comparisons, and while peak velocity and peak power were outside the limits of agreement when comparing 3-D and ED to the LPT, both variables were within limits of agreement when comparing 3-D to ED. None of these variables are directly comparable, however, they are reliable for the long-term monitoring of training variables in a practical setting.

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